

Metabolic and Subjective Results Review of the Integrated Suit Test Series

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Introduction: Crewmembers will perform a variety of exploration and construction activities on the lunar surface. These activities will be performed while inside an extravehicular activity (EVA) spacesuit. In most cases, human performance is compromised while inside an EVA suit as compared to a crewmember's unsuited performance baseline.

Methods: Subjects completed different EVA type tasks, ranging from ambulation to geology and construction activities, in different lunar analog environments including overhead suspension, underwater and 1-g lunar-like terrain, in both suited and unsuited conditions. In the suited condition, the Mark III (MKIII) EVA technology demonstrator suit was used and suit pressure and suit weight were parameters tested. In the unsuited conditions, weight, mass, center of gravity (CG), terrain type and navigation were the parameters. To the extent possible, one parameter was varied while all others were held constant. Tests were not fully crossed, but rather one parameter was varied while all others were left in the most nominal setting. Oxygen consumption (VO_2), modified Cooper-Harper (CH) ratings of operator compensation and ratings of perceived exertion (RPE) were measured for each trial. For each variable, a lower value correlates to more efficient task performance. Due to a low sample size, statistical significance was not attainable. Levels of practical significance were defined as a $3.5 \text{ ml} \cdot \text{min}^{-1} \cdot \text{kg}^{-1}$ for VO_2 , ≥ 2 for RPE and ≥ 1 for CH.

Results: Varying suit weight had the greatest impact on human performance of all variables tested. For ambulation, increased suit weight led to significantly higher VO_2 , RPE and CH at speeds $\geq 5.0 \text{ km/h}$ on a level treadmill and at grades $\geq 20\%$ at slow walking speeds of $2.7 \pm 0.6 \text{ km/h}$. For exploration tasks, suit weights of 186 and 247 kilogram-force (kgf) led to consistently lower VO_2 , RPE and CH measures when compared to suit weights of 63, 121 and 308 kgf, with the least favorable suit weight for all non-ambulation tasks at 63 kgf. Varying suit pressure caused no significant changes in performance for any tasks evaluated. Varying subject weight in the unsuited condition, so that the same weight to the ground was matched to the suited trials, showed similar results to the varied suit weight trials for ambulation. As weight increased, VO_2 , RPE and CH were all higher at the same speeds and grades, but increased at a lesser rate compared to the suited trials. Varying inertial mass showed no significant changes for any tasks evaluated. When varying CG, the directly aft, directly high and certain high and aft CG locations led to the worst performance. In 1-g conditions, subjects ambulating over unknown lunar like terrain saw an average increase of 56% in metabolic rate and 7% in total distance traveled.

Conclusions: Initial findings indicate that suit weight, CG and the operational environment can have a large impact on human performance during EVA. Systematic, prospective testing series such as those performed to date will enable a better understanding of the crucial interactions of the human and the EVA suit system and their environment. However, work remains to be done to confirm these findings. These data have been collected using only unsuited subjects and one EVA suit prototype that is known to fit poorly on a large demographic of the astronaut population. Key findings need to be retested using an EVA suit prototype better suited to a larger anthropometric portion of the astronaut population, and elements tested only in the unsuited condition need to be evaluated with an EVA suit and appropriate analog environment.

Review of Integrated Suit Tests

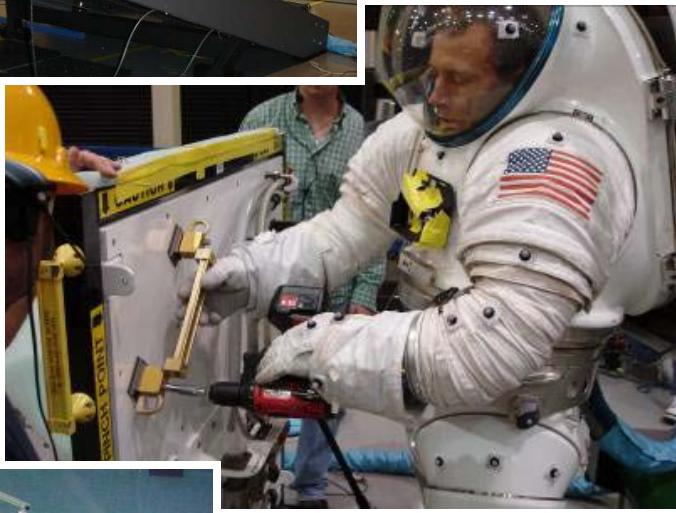
EVA Physiology, Systems and Performance Project

HRP Investigators' Workshop

February 2-4, 2009

League City, TX, USA

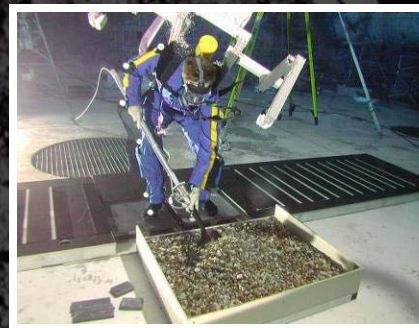
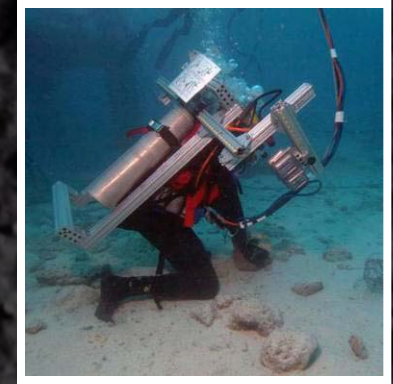
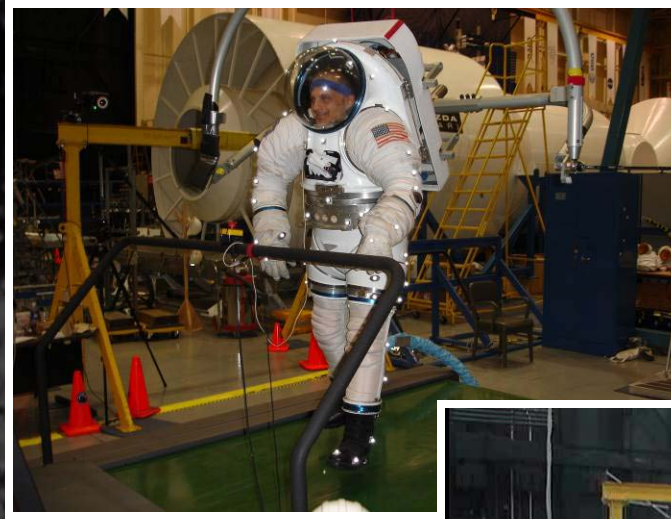
Integrated Suit Test Objectives



1. Identify the individual contributions of weight, pressure, and suit kinematics to the overall metabolic cost of the MKIII suit in its POGO configuration in Lunar gravity
2. To quantify the effects of varied weight, varied mass, varied pressure, and suit kinematic constraints on human performance in Lunar gravity
3. To develop predictive models of metabolic rate, subjective assessments, and suit kinematics based on measurable suit, task, and subject parameters

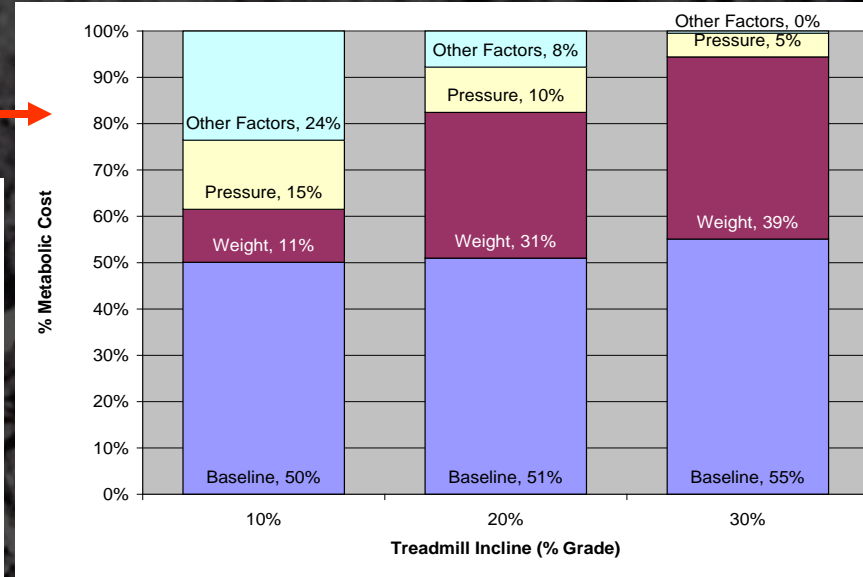
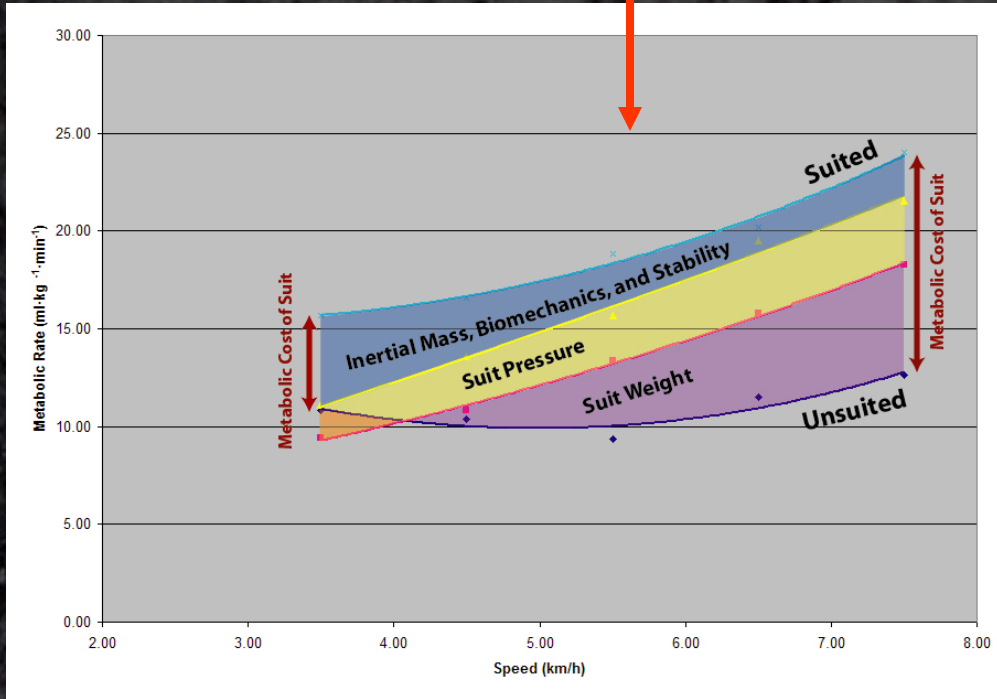
Methods

- EVA Walkback Test
 - Overhead suspension
 - Treadmill
- Integrated Suit Test 1
 - Overhead suspension
 - Treadmill
- Integrated Suit Test 2
 - Overhead suspension
 - Treadmill
 - Exploration tasks
- HMP Walkback Test
 - Overground ambulation on lunar-like terrain
- NBL/NEEMO CG Test
 - Underwater
 - Overground ambulation
 - Exploration tasks

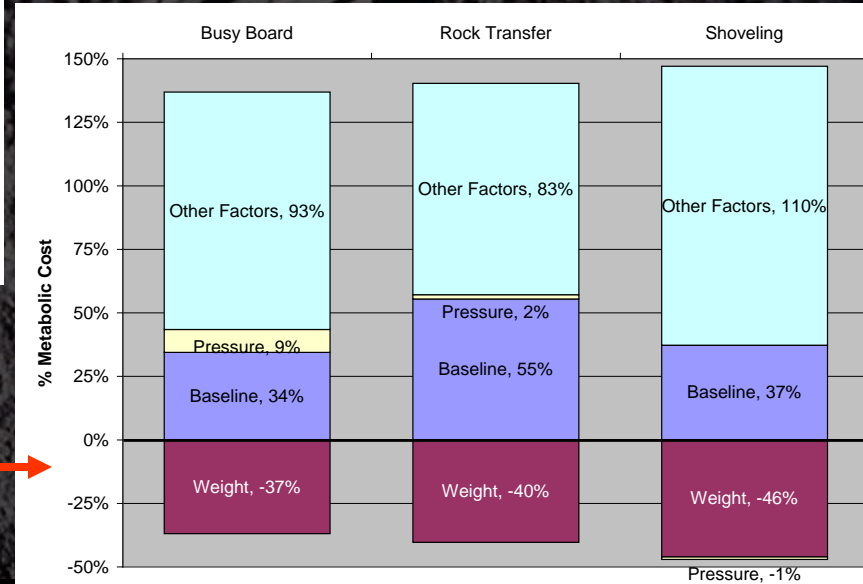


Contributions of weight, pressure and other factors to metabolic cost of MKIII in POGO configuration in Lunar gravity

Ambulation

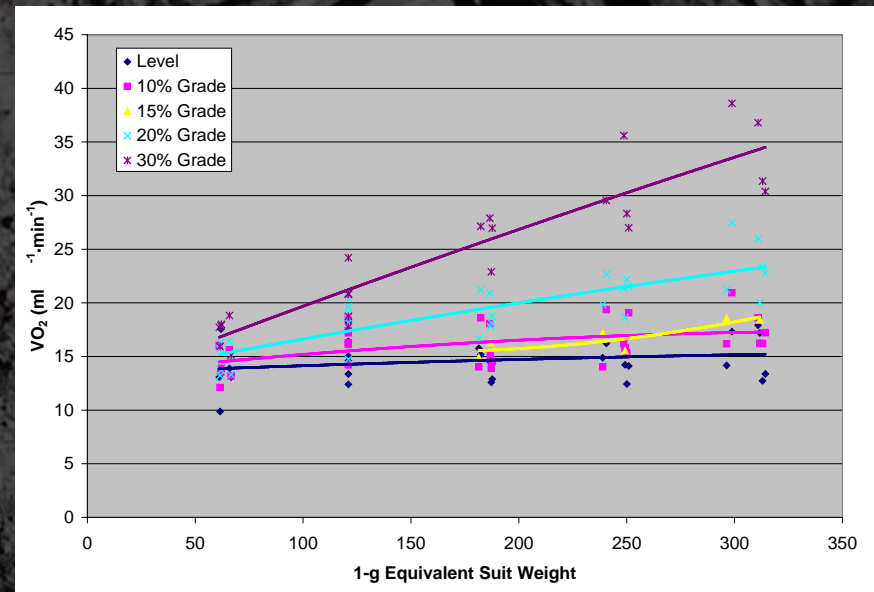
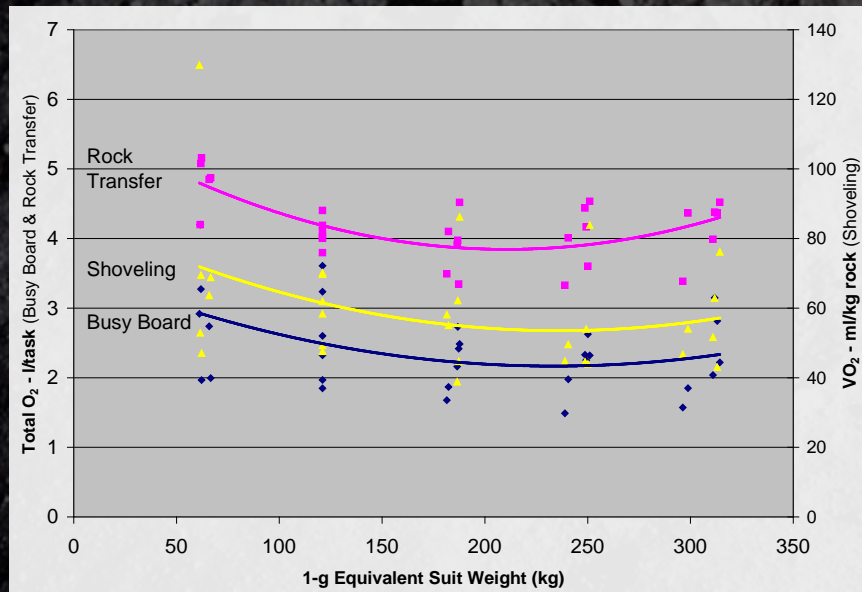
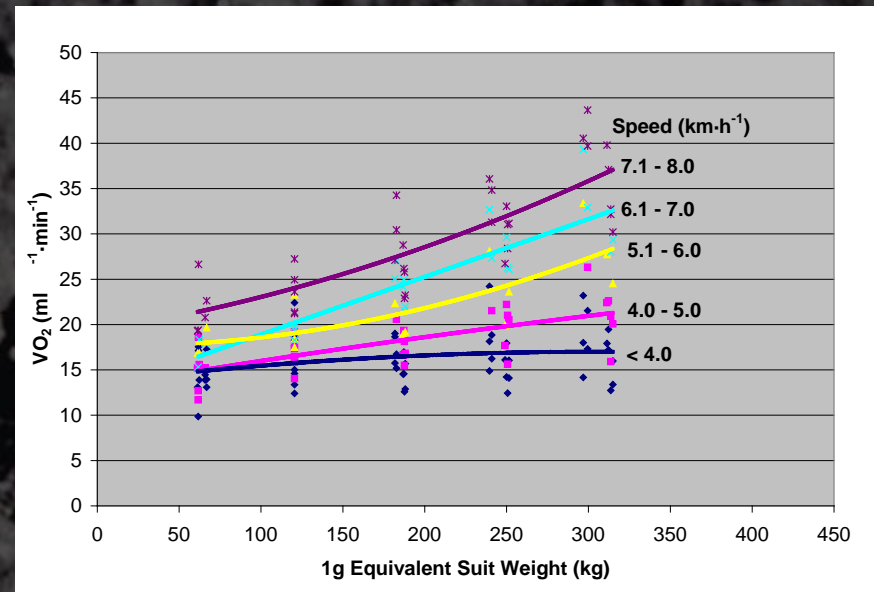


Exploration Tasks



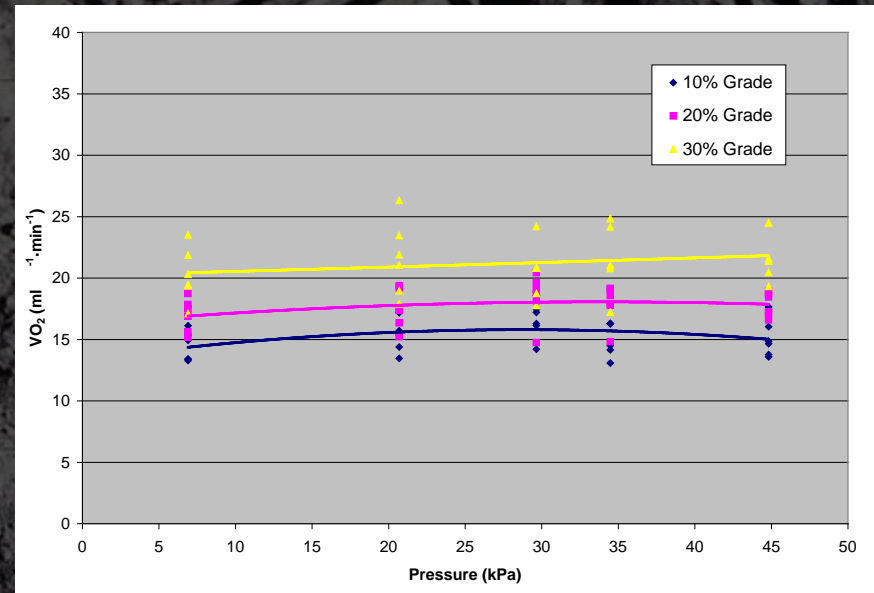
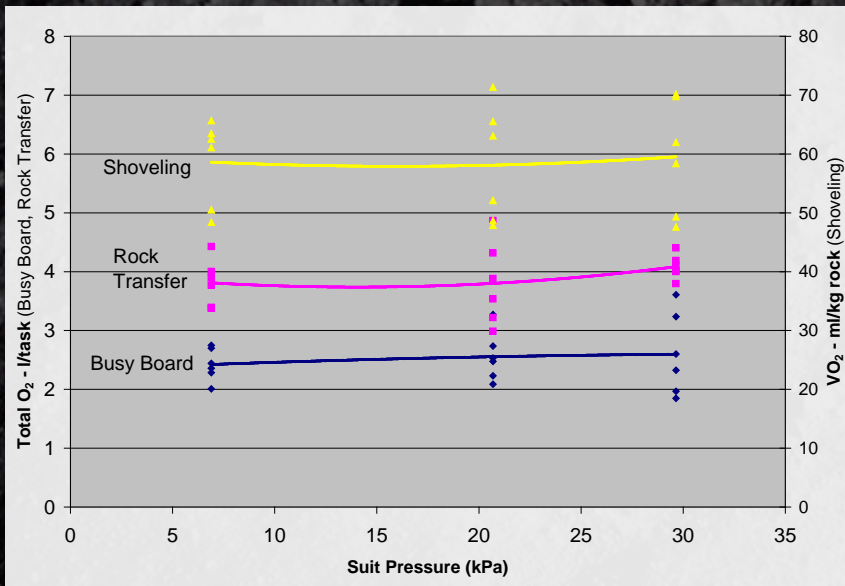
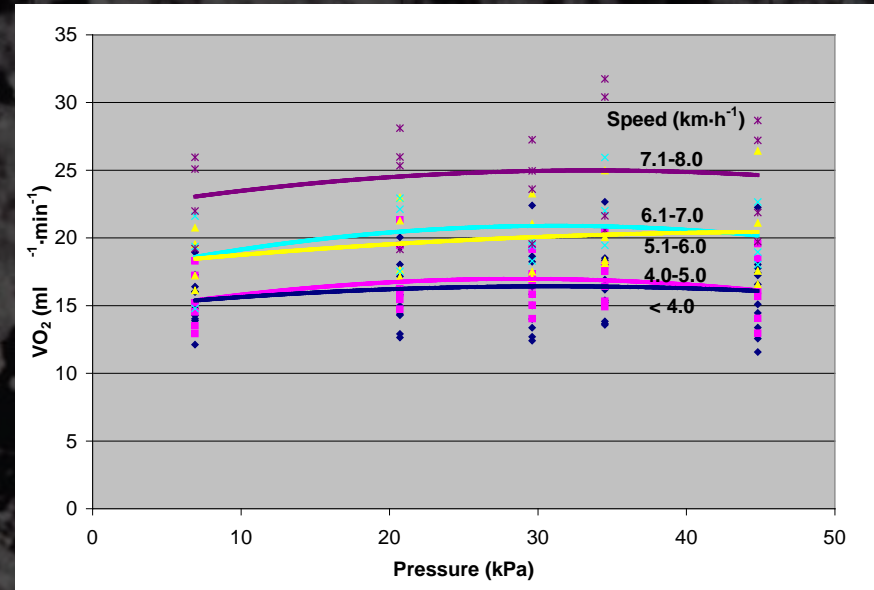
Varied Weight

- Increased suit weight improves performance of exploration tasks
- Heavier suit weights have a greater effect on ambulation metabolic rate at speeds > 4.0 km/h and at grades $\geq 20\%$

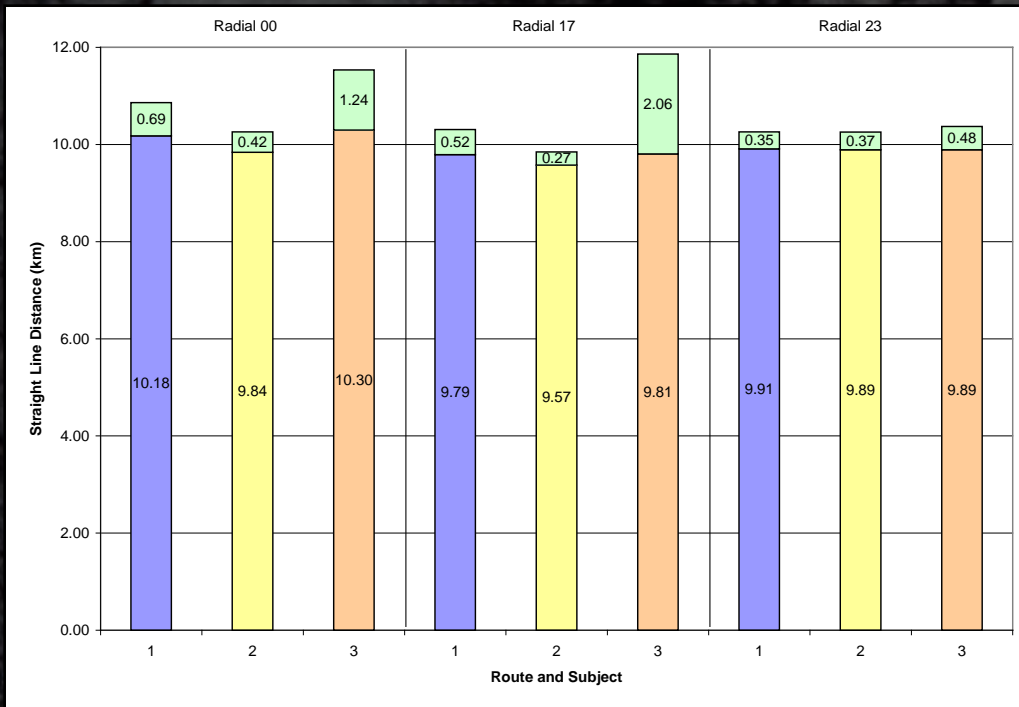


Varied Pressure

- Pressurizing the suit does cause an increase in metabolic rate when compared to an unpressurized suit
- Pressure differences from 1.0 to 6.5 psi made little impact on human performance for tasks tested



Terrain and Navigation



- ↑ VO_2 by 56% on average (range 41-67%)
- ↑ Distance by 7% (up to 21%)

Summary
(n=3)

HMP

JSC

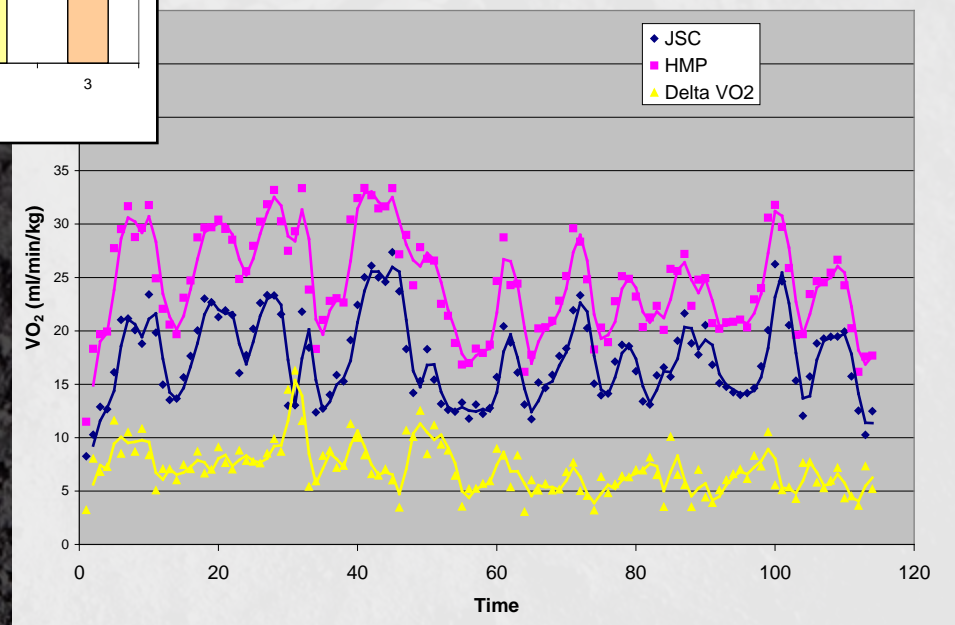
ΔVO_2

Avg VO_2
($\text{mL} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)

26.9
6.4

17.1 ±
4.9

9.8
3.8



Predictive Models for Metabolic Rate

- Inputs include subject anthropometry, suit parameters and EVA concepts
- Optimize operational concepts for EVA suit
or
- Optimize EVA suit for operational concepts

Subject Inputs		EVA Ops Con		EVA Percentages		or	EVA Time (hours)	
Body Mass (kg)	82	EVA Time (hrs/day)	6	SS Rest			SS Rest	
Height (cm)	186	Total # EVA's	12	Suited Rest			Suited Rest	
Leg Length (cm)	105	# EVA Crew	2	Intrasite (1.5-3 kmh)	25%		Intrasite (1.5-3 kmh)	0.83333333
				Site to Site (4-5 kmh)			Site to Site (4-5 kmh)	
				Walkback (>6.5 kmh)			Walkback (>6.5 kmh)	
Suit Inputs		km/h		Pick Your Speed			Pick Your Speed	
Suit Type	MKIII	Level Average Speed	5.8	10% Incline	25%		10% Incline	1
Suit Weight (kgf)	121	10% Incline Speed	5.8	20% Incline	25%		20% Incline	0.33333333
Suit Pressure (kPa)	29.6	20% Incline Speed	5.8	30% Incline			30% Incline	0.33333333
		30% Incline Speed	5.8	Decline Walking (-10%)			Decline Walking (-10%)	1.2
		-10% Decline Speed	5.8	Shoveling	25%		Shoveling	0.66666667
				Construction Tasks			Construction Tasks	0.67
		Percentages	Hours	Rock Transfer			Rock Transfer	0.67
Average Metabolic Rate (ml/min/kg)		17.0	16.9	Total	100%		Total	5.70666667
Total Oxygen per Person per EVA (L)		501.4	475.0					
Total Oxygen Per Mission		12033.3	11399.8					